RESEARCH DEPARTMENT

Line – store standards conversion: the design of video transmission lines

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LINE-STORE STANDARDS CONVERSION : THE DESIGN OF VIDEO TRANSMISSION LINES

Technological Report No. T-150

(1965/35)

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LINE-STORE STANDARDS CONVERSION : THE DESIGN OF VIDEO TRANSMISSION LINES

SUMMARY

This report discusses requirements affecting the design of transmission-lines suitable for the distribution of video signals within the store assembly of one form of line-store converter. The development of two types of transmission-line which meet the requirements defined is described.

1. INTRODUCTION

The basic constituent of a line-store standards converter[1,2] is a set of identical storage elements into which picture information is written at a rate depending on the standard of the incoming signal and from which it is read at a rate depending on the standard of the outgoing signal. The storage elements are connected in sequence to input and output circuits by a number of high-speed switches. In one form of such a converter[3] the storage elements are fixed capacitors; each is mounted, together with its associated input and output switches, on a separate printed-circuit card, the arrangement being termed a 'store unit'. It is therefore necessary to make input and output video connexions to each of the 546 or more store units that are required for conversion between the 405- and 625-line standards.[4] As a result, the common signal connexions extend over a distance of several feet, and signal delays within the interconnexion system are comparable with the time taken by a switching operation. Thus it is necessary to design the interconnexion system with care in order to prevent the introduction of interfering delayed signals due to reflexions. Moreover, it is necessary to isolate the input and output connexions from each other in order to limit direct crosstalk between them to an acceptable level.

This report outlines the requirements which influence the design of signal connexions in a converter of the above type and describes the development of a transmission-line system that has proved satisfactory in practice.

In the line-store converter, transmission-lines were used not only for conveying video signals to and from the store units but also for connexion of the clock-pulses which caused the store-unit switches to operate. Except where otherwise stated the development of the clock-pulse lines closely followed that of the video-signal lines.

2. SPECIFICATION OF TRANSMISSION LINES

2.1. Basic Requirements

It will be appreciated that the route taken by a given picture-signal sample in its progress through the converter is different to that taken by other samples from the same television line. This route, comprising input connexion, store unit and output connexion, depends on which store-unit input switch is closed at the time when the sample arrives at the input connexion. Therefore any differences between routes cause spurious vertical striations to appear on the output picture.* All store circuits should therefore be identical in operation[5] and should be presented with the same impedance by each common signal connexion. Furthermore, this impedance should be suited to the switch circuit since it will influence the store-capacitor charging action.

The interconnexion system should have a bandwidth adequate for the video signals that it is required to carry (4·6 Mc/s) and it should be designed in such a way that the charging action is not disturbed by spurious signals arising from reflexions at remote points; the effects of such reflexions would vary progressively from store to store and so the interference produced would be visible as a series of broad vertical bands superimposed on the output picture.

Another cause of spurious interference patterns on the displayed output picture is 'break-through' of unconverted input signal components into the output circuits. Such break-through arises if any coupling exists between the input and output connexion systems other than that provided by normal store-unit action. The maximum tolerable unwanted coupling has been established by means of subjective tests[6] and the results of these tests figure as an important specification in the design of the interconnexion system.

It became apparent early in the design of the converter that the best method of satisfying the above requirements would be to use a single transmission-line for the common input connexion and a second transmission-line, running parallel to the first, as the common output connexion; the store units could be arranged to straddle the two lines and could be connected to them by means of tapping points. Adjacent store units would operate consecutively. A further pair of transmission-lines similarly arranged would be used to distribute clock-pulse signals.

It was also decided at this time to drive the input line at one end of the group of transmission-lines and to extract the signal from the output line at the other end of the group. Thus all parts of the video signal would travel along the same total length of transmission-line irrespective of which store was being used, and so shading signals due to transmission-line attenuation would be avoided. A simplified diagram of the arrangement is shown in Fig. 1. For correct operation of the converter it is essential that the stored samples reach the output amplifier in a regular succession; it is also desirable, though less important, that the input signal be sampled at regular intervals. For any configuration of transmission-lines in which

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* In practice, the subjective severity of these striations may be reduced by arranging that a given vertical strip of picture is handled by adjacent store units during alternate field-periods.

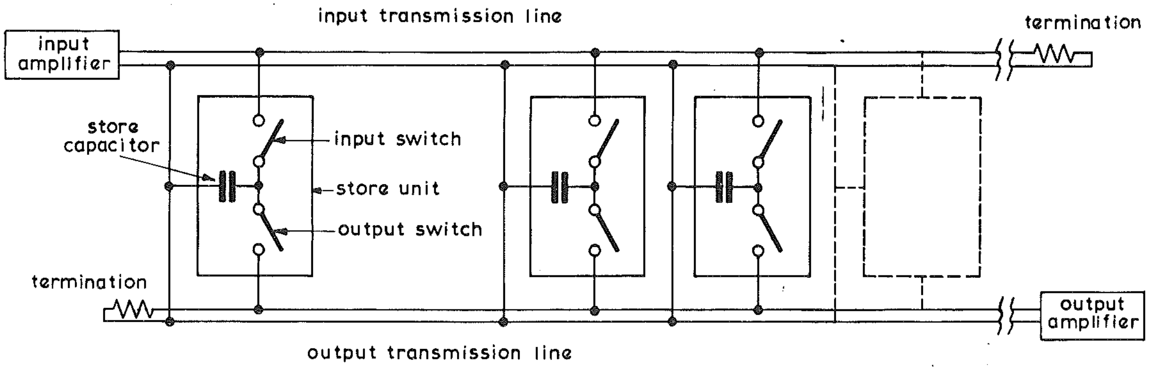

Fig. 1 - Simplified block diagram of store assembly (both lines are terminated at both ends, however the above nomenclature assists the description)

each video line runs alongside an associated clock-pulse line characterized by the same velocity of propagation, these conditions are automatically met provided only that the video signal always flows in the same direction as its associated clock pulses.

2.2. Detailed Considerations

2.2.1. Impedance

Whilst a store-unit switch is closed, the store capacitor is charged or discharged as part of a damped series-resonant circuit, half the transmission-line impedance forming about half of the damping resistance. This must be taken into account when the transmission-line impedance is chosen. Thus the impedance of the line should be sufficiently low to ensure that the charging (or discharging) current has ceased at the end of the period during which the switch is closed, yet it must be high enough as compared with the forward resistance of the diodes constituting the switch to prevent the total charging resistance from being unduly affected by the inevitable variations that occur in the values of diode resistance.[3] However, it was found that only a limited range of impedances could be easily realized if lines of the two types considered practicable were used. One type was of co-axial construction and it was found that in order to achieve uniformity with impedances of 5Ω or less, the required degree of mechanical precision would be impracticable. The other type used flat copper strips as conductors and the width of these would be inconveniently large for impedances of less than 15Ω. The upper limit of realizable impedance is decided by the fact that the line is loaded by the input capacitance of each inoperative store circuit. If an impedance of 55Ω or greater were chosen, the capacitance presented at each tapping point by the associated store unit would constitute a major proportion of the capacitance determining the impedance of the line. Thus variations in store-unit capacitance would cause irregularities in impedance.

Thus it was necessary for the designs of the transmission-lines and store units to proceed together. The impedance range most convenient for transmission-line design (20Ω to 30Ω) also proved very suitable to the store-circuit requirements, and all the lines constructed were made to have a loaded impedance within this range.

Store-circuit loading affects both the impedance of the line and its propagation velocity. As is well known, the impedance of an unloaded line is given by:

$$Z_o = \sqrt{L/C}$$

and the velocity of propagation:

$$v_o = 1/\sqrt{LC} \quad *$$

where

L = inductance per unit length

C = capacitance per unit length

If the line is then loaded by a distributed capacitance of C' per unit length, the impedance and the velocity are both reduced by a factor $\sqrt{1 + C'/C}$. The magnitudes involved may conveniently be illustrated by reference to the design of a practical line which is discussed later in this report. The effective loading by the store-units and their associated connecting sockets were estimated as contributing about 200 pF per metre. In order to realize a loaded impedance of about 26Ω it was necessary to design a line having an unloaded impedance approximating to 38Ω and distributed capacitance of some 170 pF per metre (ϵ_r assumed equal to 4). The velocity of propagation along the line was reduced, by the loading, from about 0·50 ft/ns (0·15 m/ns) to about 0·34 ft/ns (0·10 m/ns).

2.2.2. Uniformity and Terminations

When a store-unit input switch closes, the charging current drawn by the circuit produces at the switch a voltage pulse having a duration of approximately 30 ns and a magnitude proportional to the video-signal voltage existing on the input transmission-line. Two voltage waves of this form therefore travel along the line, one in each direction from the switch. Discontinuities in transmission-line impedance and errors of termination cause the video-signal and either or both of the charging pulses to be reflected. The time at which reflexions return to the region of the store circuit considered depends on the distance between the store-circuit and the discontinuity.

The output transmission-line carries voltage pulses due to the discharge of storage capacitors which occurs when successive store-circuit output switches close. These pulses are of similar duration to those produced at the input switches when the capacitors are charged, the train of pulses arriving at the output amplifier being amplitude modulated by the required video-signal. A similar train of pulses is propagated in the opposite direction, and it is intended that these be absorbed in the terminating resistor. However discontinuities in the line or errors in termination result in reflexions of these unwanted pulses, which then appear as a spurious output signal.

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* For an air-spaced line this velocity is approximately equal to c, the velocity of light in free space, and in general it is given by $c/\sqrt{\mu_r \epsilon_r}$ where μ_r is the relative permeability and ϵ_r the relative permittivity of the medium surrounding the conductors.

The effect of reflexions in the input and output transmission-lines is further discussed in Section 5.

Reflexions within the transmission-lines carrying the clock-pulses cause a mistiming of the action of those stores at which the clock-pulses and their reflexions overlap. This is relatively unimportant to the writing process, where the effect is a negligible horizontal shift of information in some parts of the output picture. However, such disturbances to the reading process affect the regular arrival of pulses at the output amplifier, and this can cause a significant error in the output signal derived by filtering.

Approximate calculations have indicated, however, that a discontinuity in the reading clock-pulse line would not produce a visible pattern unless the modulus of the resultant reflexion coefficient were greater than 1/5. Reasonable care in design should enable such discontinuities to be avoided.

2.2.3. Unwanted Coupling between Input and Output Lines

Break-through of signal from the input transmission-line to the output line can arise in two ways, which are considered in the following sections.

2.2.3.1. Coupling Due to Shared-earth Conductor

The store circuits used in the converter considered are connected by means of unbalanced transmission-lines. The earth connexion is therefore common to both input and output lines; if its resistance is significant, current in one line can produce a voltage across this resistance and so interfere with the signal voltage in the other line.

Fig. 2 shows an equivalent circuit in which two identical transmission-lines share a common earth return of resistance r. Each line is terminated by an impedance Z, and the input line, driven from a matched source, carries a current i_1. A current i_2 is induced into the output line because of the shared resistance r.

It can readily be deduced from this circuit that if $r = xZ$, $(x \ll 1)$, an interfering voltage approximately equal to $x/2$ times the input-line voltage is developed

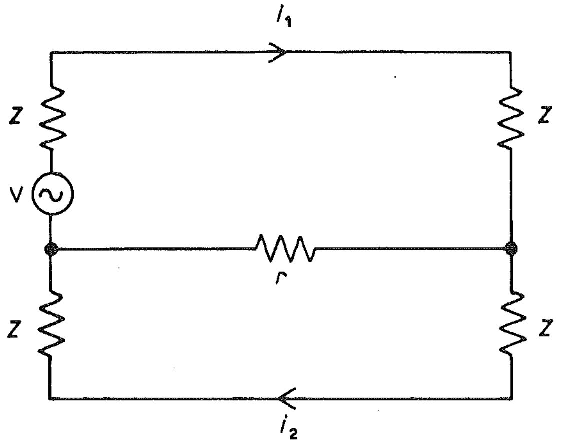

Fig. 2 - Equivalent circuit showing common earth impedance

in series with the output-line voltage. The magnitude of the video-signal component in the train of pulses carried by the output transmission-line may be shown to be about 1/30 of that of the video signal carried by the input line. It follows that for the interfering signal to be attenuated by at least 40 dB relative to the wanted output signal,[6] $x/2$ should be less than 1/3000, i.e. $x < 1/1500$. This means that for $Z = 25\Omega$, $r < 1/60\Omega$.

It is evident from Fig. 2 that the polarity of the coupled signal would be inverted if the direction of propagation of signal along the input line were reversed. If, therefore, the total length of the group of transmission-lines used in the store assembly is broken up into an even number of sections, this form of coupling can be substantially eliminated by arranging that in half of the sections the input and output signals flow in the same direction, while in the other half they flow in opposite directions.

Fig. 3 shows how this condition may be achieved by suitably interconnecting the transmission-lines of four adjacent sections of store assembly. Although the input and output transmission-lines (each with its associated clock-pulse line) link the store units in different sequences, correct operation of the converter is maintained by arranging that 'writing' and 'reading' hand-on pulses link the store units in the same sequence. This method of interconnexion violates the condition, mentioned in Section 2.1, that all paths through the converter should involve the same total length of transmission-line. The individual sections of line are, however, comparatively short, and the resultant differences in path length are not great enough to cause perceptible shading in the converted pictures.

2.2.3.2. Coupling Due to Inter-line Capacitance

In the store assembly of the converter, the input and output transmission-lines run parallel to one another for a distance of the order of 50 ft (15 m). Therefore, unless they are adequately screened, their distributed mutual capacitance and mutual inductance give rise to coupling between the lines.

If the relative directions of flow of input and output signals are reversed in alternate sections, as envisaged above, the net mutual inductance is small and the

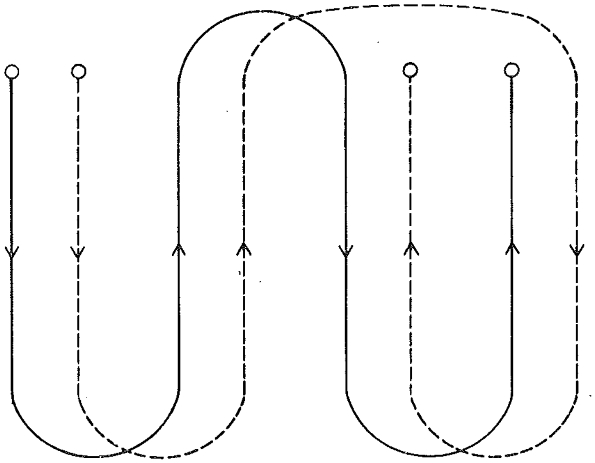

Fig. 3 - Transmission lines interconnected in such a way as to eliminate coupling through common earth connection

——————— Input transmission lines
– – – – – – Output transmission lines

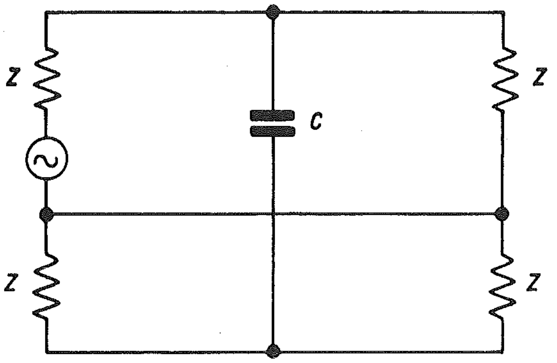

Fig. 4 - Equivalent circuit showing inter-line capacitance

coupling is predominantly capacitative. If this arrangement is not used (i.e. the lines are arranged as shown in Fig. 1) the respective contributions of mutual capacitance and mutual inductance to the coupled signal present at the output amplifier are in opposition and would, under certain ideal conditions, cancel completely;[7,8] in practice, however, the effect of capacitance is likely to predominate because of the additional capacitative coupling introduced by connexion of the store boards. Therefore, in an attempt to obtain an early estimate of the amount of inter-line screening necessary, it was decided to make the assumption that no mutual inductance would exist and hence that the inter-line capacitance would be wholly responsible for the production of interfering signals.

Considering the distributed inter-line capacitance as composed of a large number of elements, the contribution that a given element makes to the interference at the output amplifier is independent of the location of the element, since the total distance travelled by each contribution is constant. Therefore, a single lumped capacitance of magnitude equal to the total distributed capacitance may be regarded as replacing the distributed capacitance in so far as the effects of interference are concerned. The equivalent circuit is shown in Fig. 4.

Since C is small, the signal is effectively coupled to the output through a differentiating network. It has been found[6] that under these circumstances a 3 Mc/s interfering signal must be attenuated by at least 16 dB relative to the wanted output if it is to be imperceptible. The wanted signal is, as mentioned, reduced by a factor of 1/30 in its passage through the storage system; and it may be deduced that, for $Z = 25\Omega$, the total inter-line capacitance must be less than 22 pfs. to meet the requirement.

2.2.4. Mechanical Considerations

Since the transmission-lines are connected to every store unit, their design has a substantial influence on the configuration of the machine. Each store unit spans four transmission-lines and it is therefore desirable that the lines run as closely together as the coupling requirements will allow, so that their spacing does not limit the compactness of the store units.

The minimum realizable spacing between neighbouring store units depends on the way in which they are mounted and on the degree to which stray fields associated with one store are able to influence the working of adjacent stores. The spacing of stores, of course, affects the degree to which the transmission-line is loaded and hence the impedance that the unloaded line should be designed to have.

Transmission-line construction is also affected by the method of connexion of store units to tapping points. If soldered or other semi-permanent connexions are made, ease of servicing requires either that each store unit should be very readily accessible or that it should be easily possible to remove an appropriate length of line, together with the attached stores. On the other hand if store units are connected by means of plugs and sockets the transmission-lines may be made a fixture, provided that store units are readily accessible.

Both of the above methods were tried in the development of the converter, and very different mechanical constructions resulted.

3. DEVELOPMENT OF PRACTICAL TRANSMISSION-LINES

Several forms of transmission-line were constructed during the development of the converter and two types will now be discussed. Both were of rigid construction, forming part of the framework upon which the store units were mounted.

3.1. Co-axial Transmission Lines

Whilst the converter was in an early stage of development it was decided to design both the store-unit layout and also the transmission-line system so as to minimize as far as is practically possible the crosstalk between the input and output circuits.

Fig. 5 shows the arrangement used. The transmission-lines were of square co-axial cross section of approximately ½in (12·7 mm) outer dimension, their construction being as shown in Fig. 6. The inner conductors were located by means of 8BA brass

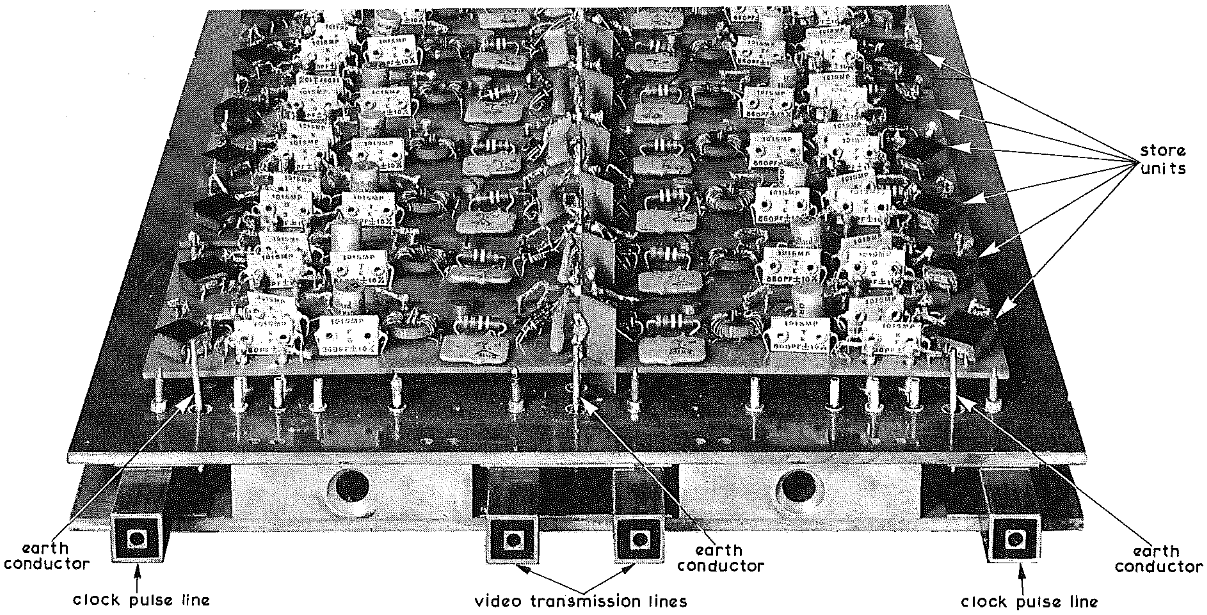

Fig. 5 - Store assembly layout using co-axial transmission-lines

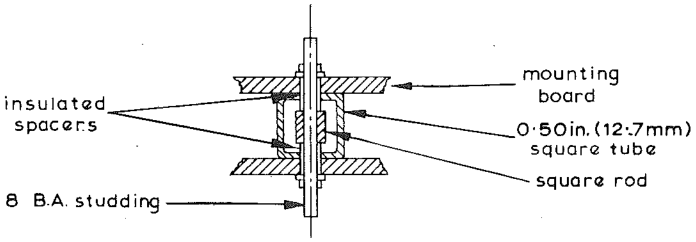

Fig. 6 - Construction of co-axial transmission-lines

studs and insulating spacers, with the studs projecting on each side through insulated mounting boards to become the taps to which circuit connexions were made. The store-unit printed-circuit boards[3] were drilled to allow the taps to pass through them and soldered connexions were then made to them through pigtails of copper braid. Earth connexions were provided at each tapping point by means of pegs returned to brass plates sandwiched between the transmission-lines and the mounting boards. The additional pegs shown in Fig. 5 supplied power and 'hand-on' connexions.[3]

The layout of the store assembly was such that individual store units were not readily accessible. The experimental store assembly, containing 84 store units in all, was therefore divided into two sub-assemblies, each containing 42 store units. The store units visible in Fig. 5 were some of the 21 units that lay above the plane of the transmission-lines; a further 21 units, not visible in the Figure, lay below this plane. The sub-assemblies were located by means of the grooves formed by the clock-pulse transmission-lines and the edges of the mounting boards. The ends of the transmission-line sections were designed to plug into U linkages of similar cross section.

In order to determine the cross sectional dimensions of the line necessary to produce the required impedance, a resistive analogue technique was used. This technique is possible because the electrostatic flux which exists between two conductors of different potential in a dielectric medium takes up the same distribution as the current flux between similarly disposed conductors in a resistive medium.

The total electrostatic flux within a dielectric medium defines the charge q, on the conductors, whereas the total current flux between conductors in a resistive medium defines the current I. The similarity of the two flux distributions means that similarly altering the configuration of both pairs of conductors (at constant voltage difference, V) changes q and I by the same factor. Thus, the capacitance C between two conductors in a dielectric medium is inversely related to the resistance R between corresponding conductors in a resistive medium. For a given dielectric the capacitance of a transmission-line is also inversely related to its characteristic impedance Z_0 and the value of Z_0 thus varies directly with the resistance of the resistive analogue.

Moreover, since electrostatic flux within a uniform loss-less transmission line is everywhere at right angles to the conductors, a two-dimensional resistive analogue describing a transverse cross-section may be used. The constant of proportionality relating the resistive analogue to the cross-section of an actual line may be determined by constructing the analogue of a line whose impedance may be easily calculated from a knowledge of its dimensions.

In this way, the impedance of a square co-axial line was determined. The analogue was constructed using a paper which had been uniformly impregnated with carbon so as to make its resistance equal to 2 kΩ per square.* Conductors were drawn on the paper using a silver paint of high conductivity.

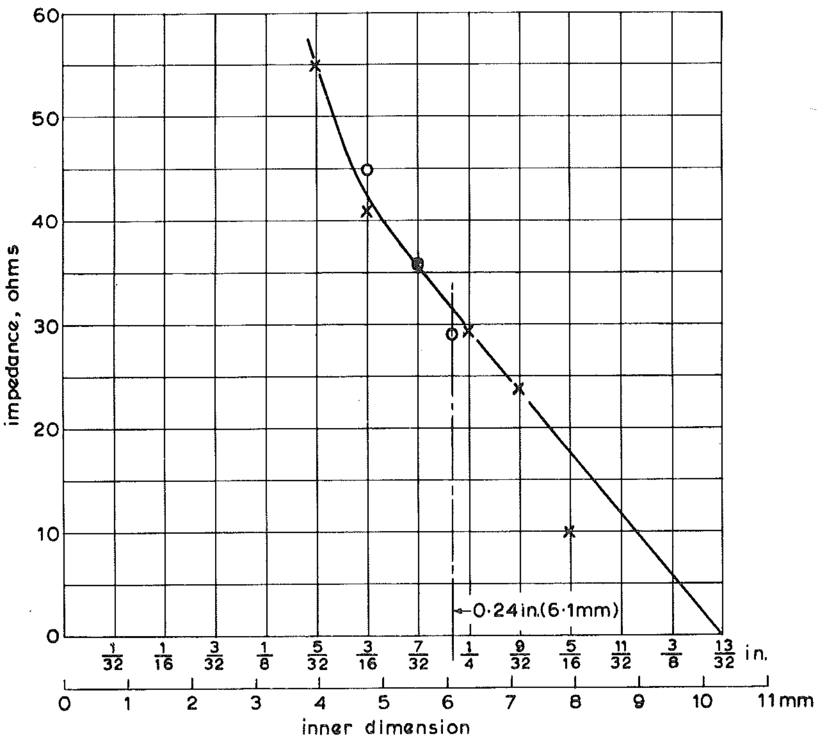

Fig. 7 - Square co-axial transmission-line impedances as predicted by resistive analogue and as deduced from measurements of inductance and capacitance per unit length

A circular co-axial cross-section was first constructed as a reference by means of which the analogue was 'calibrated'. Thereafter square co-axial cross-sections were drawn. A fixed outer was used, first with a very small inner, and then with successively larger inners, measurements of resistance being made at each step. These measurements gave data from which the graph shown in Fig. 7 was constructed.

Three experimental sections of line were made, each using, as the outer, a square tube of ½ in (12·7 mm) outer dimension and 18 SWG thickness, with square inners of 0·24 in (6·1 mm), 3/16 in (4·8 mm), and 7/32 in (5·6 mm). Their impedances were computed from measurements of inductance and capacitance per unit length and were found to be lower than those predicted by Fig. 7. This was largely due to the additional capacitance introduced by the studs and spacers. Half of the studs and spacers were therefore removed, and the line capacitance was again measured. By this means an allowance could be made for tapping-point capacitance and when this was done the measured impedances shown in Fig. 7 resulted. Agreement between the predicted and measured impedances is good, considering the limited accuracy of the resistive analogue and the tolerances achieved in transmission-line construction.

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* i.e. the resistance between opposite sides of a square of any size is 2 kΩ.

For the experimental store assembly (shown in Fig. 5) transmission-lines having 3/16 in (4·8 mm) inners were used which, in the absence of taps, would have resulted in line impedance of about 45Ω. This impedance was lowered to about 35Ω by the taps and spacers and then to about 26Ω by the stores and earthing plates.

The assembly constructed in this way housed a total of 84 store units. Its performance was entirely satisfactory. However, at this time a reappraisal of the mechanical design of the store assembly was made and it was considered desirable to reduce the size of the store units and to attempt the development of a simpler and more compact configuration of store-units and transmission-lines. These considerations led to the system which will now be described.

3.2. Strip Transmission-Lines

Strip transmission-lines manufactured from double-sided printed circuit board have been in use for a number of years as a means of transmitting signals at microwave frequencies.[9,10] They have the advantages of light weight, compactness and simplicity, and they can be made with great precision. It was therefore thought that they might offer a very convenient solution to the problem in hand.

At the same time it was decided to attempt a reduction in the size of the store-unit circuit boards and to make them easily and separately detachable by the use of printed-circuit edge connectors, the sockets being made permanent fixtures connected to the transmission-line and power-supply systems.

These measures all tended to increase the unwanted stray capacitance coupling unconverted signals to the output, and it was therefore necessary to ensure that the limit calculated in Section 2.2.3 was not exceeded.

The 24-way sockets were first examined. It was found that if all pins of one socket, other than those making the video connexions to the two transmission-lines, were left unconnected, the total inter-line capacitance introduced by connexion of 600 such sockets would be about 144 pfs. This could be reduced to about 42 pfs if pins between the video connexions were earthed and would be no greater than 2·4 pfs if, in addition, each socket were shrouded by an earthed screen. Suitable shrouds were therefore provided.

Fig. 8 shows the way in which the transmission-lines were constructed. The 'live' conductors were formed by removing the copper coating from the upper surface of the printed circuit board so as to leave narrow strips. The copper coating which covered the reverse side of the board formed the common earth connexion. Additional strips were left on the copper surface of the board to provide earth and power connexions.

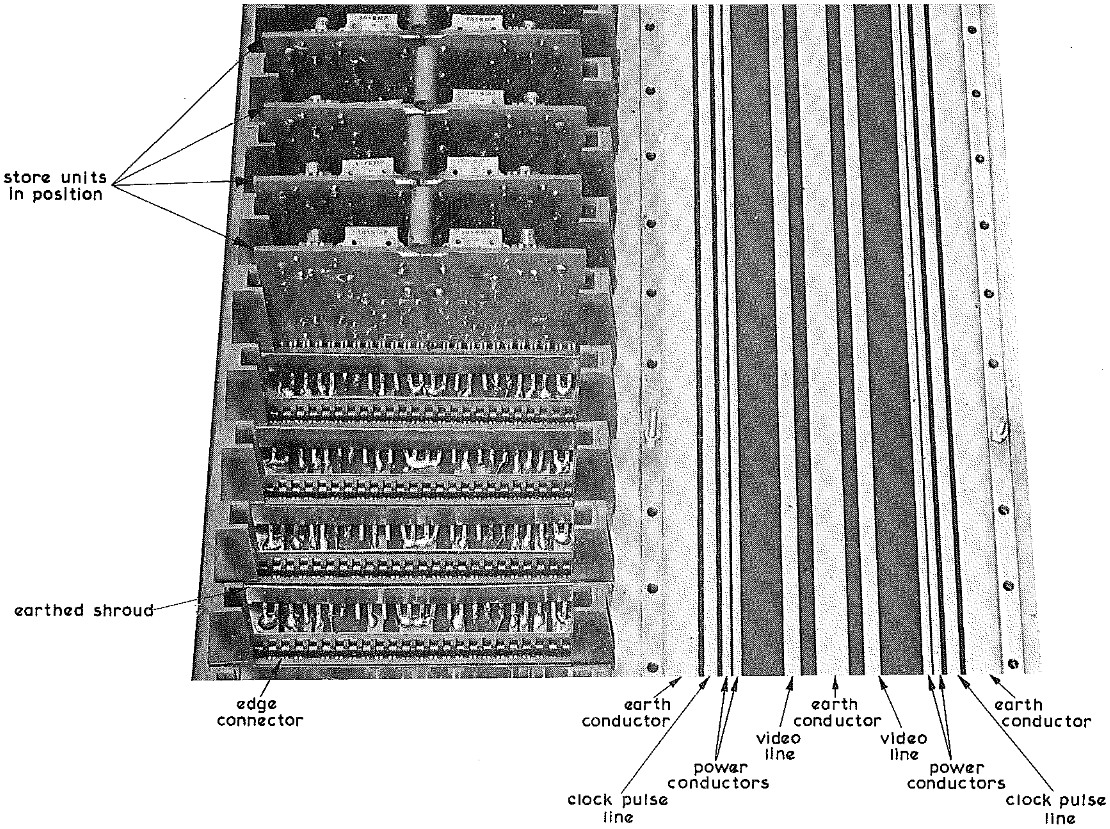

Fig. 8 - Store assembly layout using strip transmission-lines

The transmission-lines were designed to have a loaded impedance of 25Ω. The spacing between adjacent store units was to be 7/8 in (22·2 mm) and it was estimated that each store unit, with its connector, would load the line with a capacitance of 5 pF. The relative permittivity of the base material used for the lines was taken to be 4.

From these parameters it may be deduced by means of the formulae given in Section 2.2.1 that the line must have an unloaded impedance of 37·5Ω.

Published curves[10] show that for a base material of relative permittivity 4 and thickness 0·06 in (1·57 mm) the strip should have a width of 0·21 in (5·34 mm) for an unloaded impedance of 37·5Ω. Practical tests on an experimental board indicated that a width of 0·19 in (4·83 mm) was necessary; this small difference probably occurred because the relative permittivity was not exactly equal to 4. A diagram showing the dimensions finally used is given as Fig. 9.

Tests on an experimental layout having the above dimensions indicated that the total capacitance coupling the input and output lines as constructed would be of the order of 3·8 pfs but that this would be approximately halved when the earthed socket-shrouds were in position; this reduction of the capacitance between the lines themselves was fortuitous, the shrouds having been installed in order to reduce capacitance between the contacts of the connectors.

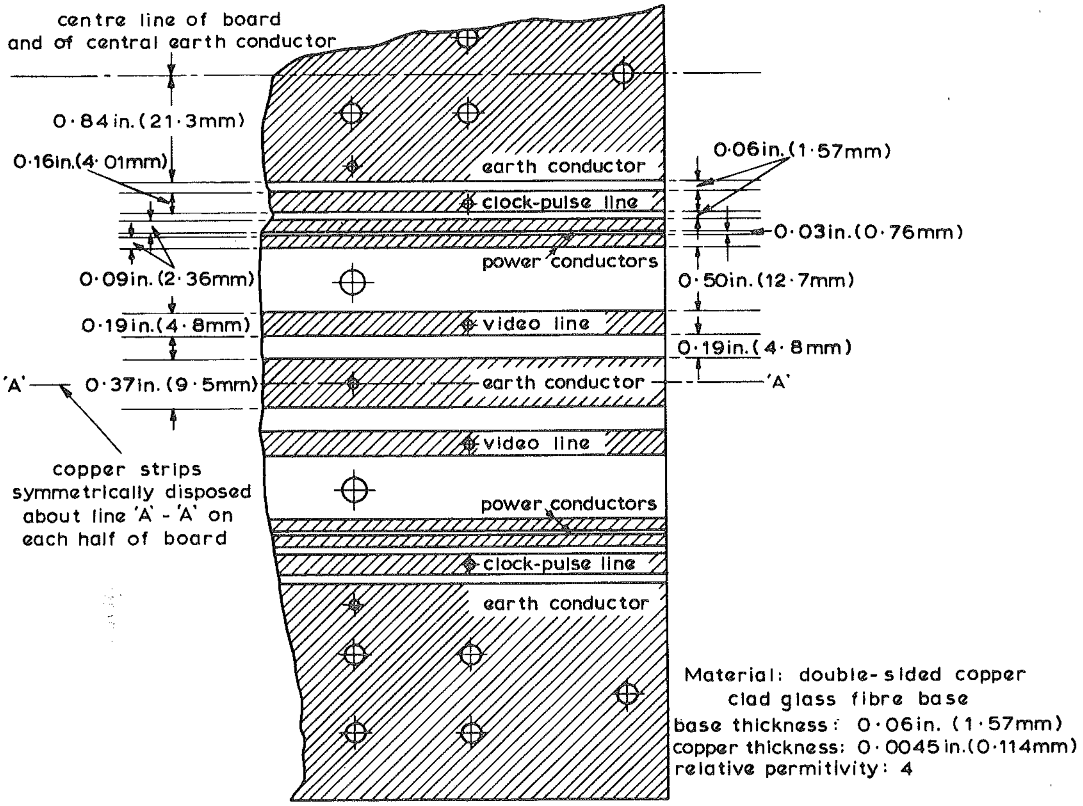

Fig. 9 - Construction of strip transmission-lines

The coupling capacitance may be estimated by use of the formula deduced in the Appendix. This formula neglects the fact that the fields produced by the lines are somewhat confined by the high permittivity of the printed circuit board and consequently leads to the pessimistic estimate of 5•1 pfs.

Fig. 8 also shows that the store-unit sockets were attached to the transmission-line system by bending the pins of the socket to make contact with the strips and then soldering to form the connexion. The four central pins were soldered to an earthing strip which was connected to the copper coating on the reverse side of the board at each store position by means of a wire passing through a hole in the board. The shrouds were earthed at both ends by means of the fixing screws.

The prototype converter was constructed in this way, the store assembly being divided into two halves, one mounted on each side of the machine. A photograph of the machine showing half of the store assembly is reproduced as Fig. 10. The complete assembly comprised sixteen sections of multiple-strip line, as illustrated in Fig. 8, arranged in pairs in which one section was joined 'end-on' to a second section. Each pair of sections was associated with 72 store units and the pairs of sections were connected together by cables of the appropriate impedance. The total length of multiple strip line was 45 ft (13•72 m). The connexions were made in the way discussed in Section 2.2.3.1, in order to produce cancellation of 'break-through' signals developed across the finite impedance of the common earth connexion. The clock-pulse signals were arranged to travel in the same direction as the associated video signals in order to ensure that correct timing was maintained.

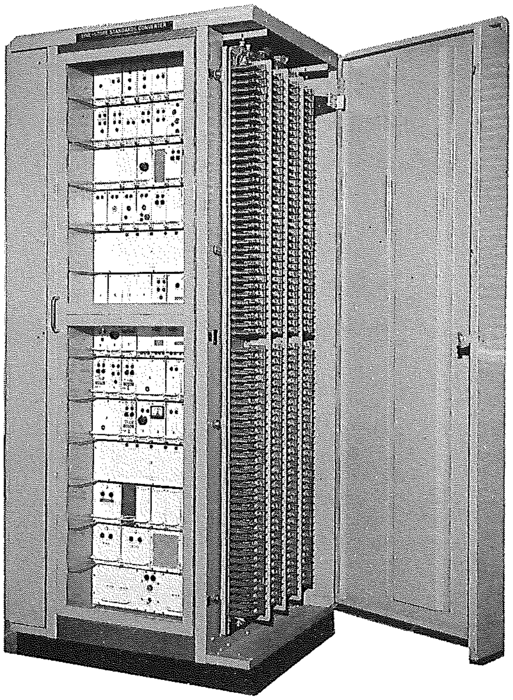

Fig. 10 - Prototype machine showing half of store assembly

The performance of the prototype store assembly was generally satisfactory; however, some broad stripes were just visible in plain areas of the converted picture, indicating transmission-line irregularities. The main cause of these is thought to have been slight mis-match between the pairs of sections of line and the 25Ω co-axial cables joining them.

4. MEASUREMENTS MADE ON PROTOTYPE MACHINE

Transmission-line measurements were made on the prototype machine at the stage when one half of the store assembly was complete and working as part of the standards converter. The second half of the assembly was installed but was not connected to the first half, nor were its store units inserted.

The capacitance of each of the video lines in the second half of the assembly was first measured and found to be 1845 pfs. Next the velocity in each line in the second half was determined by injecting a pulse of short rise-time and measuring the time taken for it to return from the open-circuited end. This gave a velocity of 0•41 ft/ns (0•12 m/ns). (This should be compared with 0•50 ft/ns (0•15 m/ns) in the line before loading by socket capacitance and 1 ft/ns (0•30 m/ns) which is the velocity in an unloaded air-spaced line.) It was therefore deduced that, at each tapping point, the loading produced by the socket alone was 1•93 pfs. The impedance of the lines in this condition was 31Ω.

A similar pulse was then added to the video waveform during the line-blanking period. By this means the velocity of signals within the first ('working') half of the store assembly was measured and found to be 0•32 ft/ns (0•098 m/ns). Since capacitative loading reduces velocity and characteristic impedance by the same factor, it was deduced that the impedance of the fully loaded line was 24Ω. This corresponds to a total loading of about 5•7 pF at each tapping point, as compared with the value of 5 pF estimated previously.

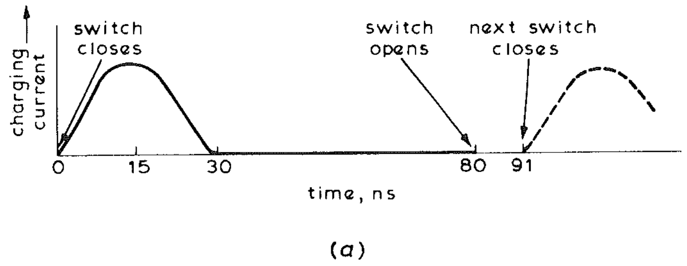

Fig. 11 - (a)
Store unit charging current

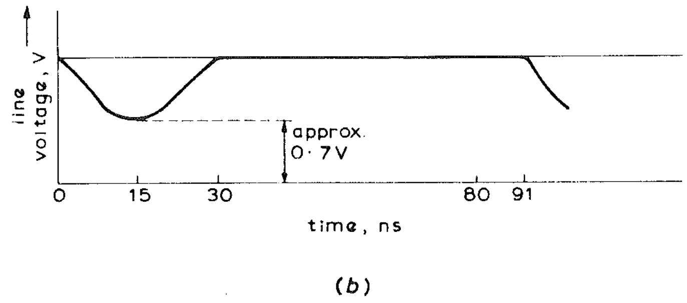

Fig. 11 - (b)
Voltage pulse produced at input to store

5. REFLEXIONS WITHIN THE TRANSMISSION-LINES

The effects of mis-termination of the transmission-lines, and of mis-match between adjoining sections of the lines, will now be considered qualitatively.*

5.1. Reflexions in the Input Line

One effect of a mis-termination at the 'terminated' end of the input line is to produce an echo whose delay is a function of horizontal position in the converted picture. The total time taken to traverse the line is about 140 ns and the direct and reflected signals are therefore separated by a maximum interval of about 280 ns (i.e. about three picture elements). Virtual imperceptibility of such echoes requires the level of the reflected signal to be more than 32 dB below that of the direct signal[12] corresponding to a maximum permissible mis-termination of ± 5%. No echoes were, in fact, perceptible in pictures derived from the complete converter. There is, however, a further consequence of the reflexion of video signals in the input line.

When a store-unit input-switch closes, current is taken from the transmission line as the store capacitor is charged, and the video voltage is correspondingly reduced. This current is shown diagrammatically in Fig. 11(*a*). It will be seen that although charging is virtually complete after 30 ns the switch is kept closed for 80 ns in order to render the stored charge independent of the precise value of the store-unit's charging time-constant; the total period between clock-pulses is, for the 625-line standard, 91 ns.

Whilst the store-unit is taking current, a voltage pulse is produced at its input. This 'charging pulse' may typically be of the form shown in Fig. 11(*b*). Its duration is approximately 30 ns, and its peak magnitude about a third of the undisturbed video-signal level.

* This Section includes an outline of some considerations by G.D. Monteath.

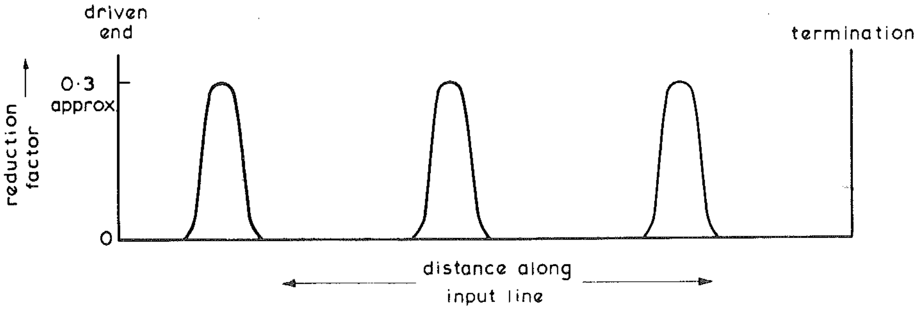

Fig. 12 - Reduction of reflected video-signals by reflected charging pulses, measured at the times when store switches operate

A pulse of this type is propagated in either direction along the transmission line. If the line is mis-terminated at either end or contains discontinuities, reflected charging pulses may be returned to the region in which they were generated at such times as to interfere with the signal being stored by the circuit that produced them, or by the next or even the next-but-one store to operate. The phenomenon will be discussed for the case where a single reflexion is produced by mis-termination at the non-driven end of the transmission-line. The effect of a reflected charging pulse is then to reduce the magnitude of the reflected video-signal encountered at a given store-unit for about 30 ns in each 91 ns period. Because of its short charging time-constant, the signal stored by a store-unit is determined only by those signals reaching it during the latter part of the 80 ns period for which its input switch is closed. Thus a store-unit is affected by a reflected charging pulse only if the unit's position along the line is such that it is subject to the pulse during this critical period. Fig. 12 shows the factor by which the reflected wave is effectively reduced, as a function of the position of the store-unit. The right-hand peak corresponds to store-units that are affected by the reflexion of their own charging pulses; the central and left-hand peaks correspond to store-units affected by the reflexions of pulses from the previous and next-to-previous store-units respectively. Thus, in plain areas of the picture, the change of video level associated with reflexion from a mis-termination is modulated by the reduction factor shown in Fig. 12, and non-uniformity of video level is produced in the form of broad vertical bands.

Where a single discontinuity occurs abruptly somewhere within the line, effects similar to those described apply between the discontinuity and the driven end. Between the discontinuity and the non-driven end of the line, banding still occurs, but now results from reflexion of the charging pulses that are propagated towards the driven end.

The spectrum of the charging pulses has been estimated as extending to 30 Mc/s, and it is therefore important to achieve low values of series inductance and shunt capacitance in the termination of the line, in order to maintain satisfactory matching up to this frequency.

In the prototype converter, banding attributable to reflexions in the input line was just perceptible to trained observers, but was not sufficiently severe to cause significant degradation of the overall picture quality.

5.2. Reflexions in the Output Line

The wanted signal on the output line consists of a train of discharge pulses produced at the times of closure of store-circuit output switches; The pulses are of similar shape and duration to the charging current pulses shown in Fig. 11(*a*), and the train is amplitude modulated by the required video-signal.

If a discontinuity occurs within the line, all discharge pulses originating at store locations between the discontinuity and the termination (see Fig. 1) are proportionately modified in amplitude as they pass the discontinuity. Pulses originating near to the discontinuity but on the other side, and travelling towards the output amplifier, are equally modified by the superimposition of reflected pulses of negligible delay. As the point of origin moves away from the discontinuity towards the output amplifier, a delay accumulates between the required discharge pulse and the reflected pulse. The effect of a discontinuity in the output line is thus to produce an echo whose delay is a function of horizontal position; but, as stated in connexion with the input line, no such echoes were in fact perceptible in the converted picture, indicating that a satisfactory degree of transmission-line uniformity had been achieved.

6. CONCLUSIONS

The design of a transmission-line system for a line-store converter is largely determined by the parameters and layout of the store circuits which it feeds, together with the requirement of low inter-line capacitance. In turn, the method chosen plays a deciding influence in the design of the store assembly. Two suitable types of transmission-line have been developed. Of these the strip-line system is preferable, on grounds of cheapness, reliability and ease of construction.

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APPENDIX*

Mutual Capacitance between Strip Transmission-lines

Fig. 13 represents a cross-section through a pair of strip transmission-lines A and B each of which have spacing d between the strip and the ground plane and are separated by a distance D. Line A carries a charge $+q$ per unit length and it is assumed that the lines are air-spaced.

So far as electrostatic fields are concerned, the ground plane may be replaced by images of the two strip conductors in the manner indicated in Fig. 14, provided that the line PQ which replaces line A also carries a charge q per unit length. The strip lines A and B may thus be replaced by the balanced transmission-lines PQ and RS.

If D is sufficiently large compared with the other dimensions, the charges may be regarded as located at the centres of the strips P and Q. Then the electric force E at the centre of the space between conductors R and S is the resultant of the two forces E' produced by $+q$ and $-q$ separately.

i.e.

$$E \doteq 2E' \text{ Sin } \theta$$

where θ is the angle between the forces E' and the neutral plane.

$$\doteq 2 \frac{q}{2\pi\epsilon_0 \sqrt{D^2 + d^2}} \cdot \frac{d}{\sqrt{D^2 + d^2}}$$

$$\simeq \frac{qd}{\pi\epsilon_0 D^2}$$

since $D >> d$.

Returning now to Fig. 13, the same force E will be present within line B due to the charge on line A, and may regarded as constant within line B.

Therefore the potential induced in line B is

$$Ed = qd^2/\pi\epsilon_0 D^2$$

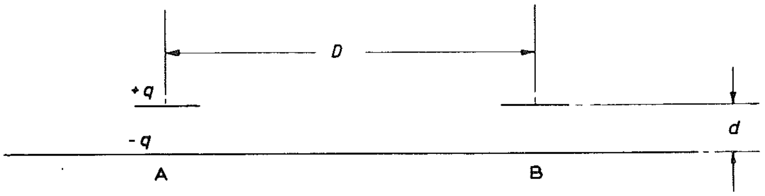

Fig. 13 - Cross section of two strip transmission-lines immersed in a uniform dielectric

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* This Appendix is based on work contributed by J.B. Izatt

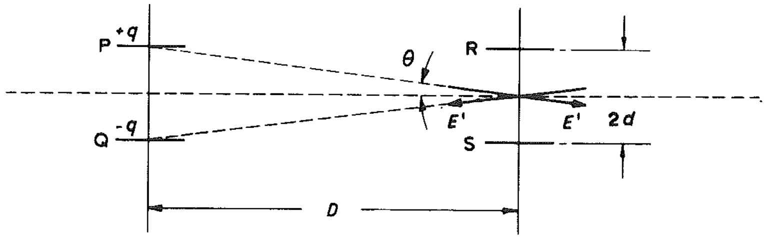

Fig. 14 - Cross section of a pair of transmission-lines having a field pattern similar to that of the arrangement shown in Fig. 13

Now if the lines have capacitance per unit length equal to C_o, and the voltage applied to a line A is V, then

$$q = C_oV$$

Moreover the voltage induced into line B will be

$$VC_m/C_o$$

where C_m is the mutual capacitance

Therefore:

$$VC_m/C_o = C_oVd^2/\pi\epsilon_oD^2$$

$$C_m = C_o{}^2d^2/\pi\epsilon_oD^2$$

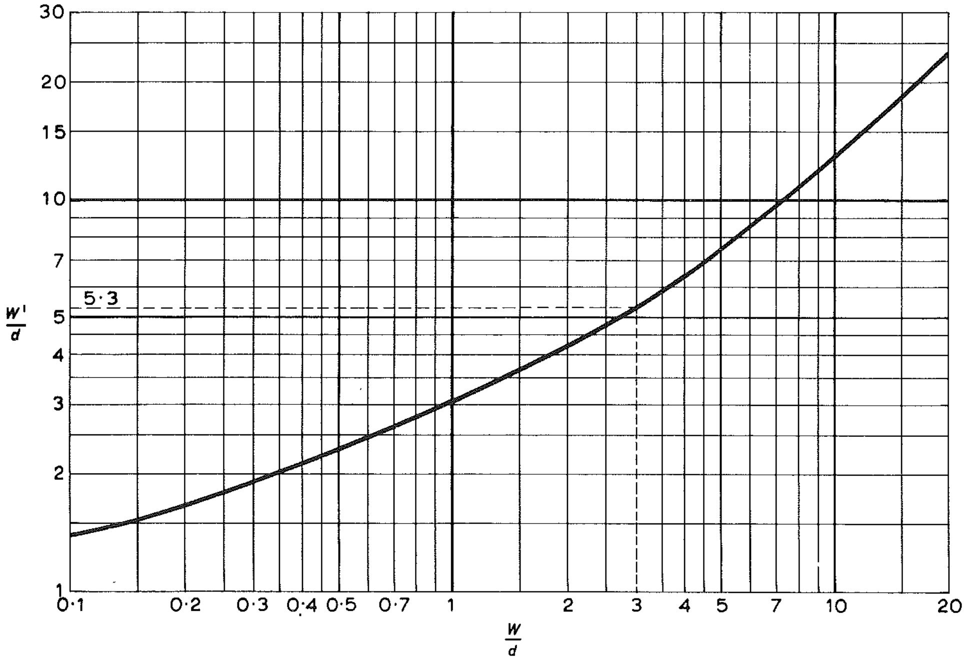

Fig. 15 - Graph for obtaining w'/d from w/d

In the absence of fringing fields, C_o would be $\epsilon_o w/d$ per unit length, where w is the width of the strip. The existance of fringing may be allowed for by taking $C_o = \epsilon_o w'/d$, w' being termed the 'effective width'.

Fig. 15 is a graph* which may be used to obtain w'/d from w/d. C_m may therefore be expressed as

$$\epsilon_o w'^2/\pi D^2$$

Using the dimensions of the lines constructed for the prototype machine, we obtain $w/d = 3$, so that $w'/d = 5{\cdot}3$.

So, since $w = 3/16$ in (4•8 mm), $w' = 5{\cdot}3/16$ in.

$$D = 15/16 \text{ in } (23{\cdot}8 \text{ mm}), \text{ and } \epsilon_o = 8{\cdot}854\ 10^{-12}$$

Therefore, $C_m = 0{\cdot}35$ pfs/metre

$= 5{\cdot}1$ pfs per 48 ft (13•72 m).

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* This graph was derived from information given in Fig. 8 of reference 11.

SMW

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